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RODENT DAMAGE IN HAWAIIAN MACADAMIA ORCHARDS

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ABSTRACT: Roof rats (*Rattus rattus*) damage an estimated 5-10% of the annual macadamia nut crop in Hawaii, resulting in farm value losses of between $2-4 million. The Denver Wildlife Research Center field station in Hilo, Hawaii studies the biology, impact, and control of rodent pests in Hawaiian agricultural crops. This paper describes field and laboratory research currently being conducted to address rat problems in macadamia nut orchards.

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INTRODUCTION

Hawaii is the world leader in the commercial production of macadamia nuts. During the 1990–91 crop year, Hawaiian growers produced 25,000 metric tons (wet inshell weight) of macadamia nuts with a statewide farm value of $41 million (Hawaii Agricultural Statistics Service 1990). This comprised 67% of total world production.

Macadamia nut orchards in Hawaii provide an ideal habitat for roof rats. Mature trees form thick canopies that provide nesting sites and interlocking branches that facilitate the safe movement of rats among trees. The lava rock substrate in orchards forms natural ground cavities and crevices where rats can burrow and nest beneath the orchard floor. Mature macadamia nuts are composed of 75–79% oils and are a rich source of energy. Windbreaks and adjacent noncrop wastelands provide alternative food when macadamia nuts are in short supply.

Macadamia nut trees produce flowers over a period of several months, with a correspondingly extended harvest from about August to February in the northern hemisphere (Cavaletto 1983). Individual nuts take about 215 days to mature, after which they drop from the tree and are harvested from the ground, either mechanically or by hand. At any time orchards contain nuts at various stages of development, thus providing rats a continuous availability of nuts throughout the year.

Rats damage an estimated 5–10% of the annual macadamia nut crop in Hawaii, causing farm losses ranging from about $2–4 million. Damage occurs throughout the crop cycle, from the time kernels are small, fleshy, unprotected fruits to when they are fully developed and surrounded by husks and hard, brittle shells. The majority of damage occurs to nuts hanging in trees, with only limited foraging occurring on fallen nuts.

CONTROL PRACTICES

Few methods are effective for controlling rat populations in orchards. Prompt removal of pruned or fallen branches and other debris helps to reduce harborage for rats in orchards and windbreaks, but populations continue to thrive in both areas. The small Indian mongoose (*Herpestes auropunctatus*) (Tomich 1986:95-96) and the barn owl (*Tyto alba*) (Tomich 1962) were introduced into Hawaii to control rat populations, but neither predator provides significant control of economic damage. The rodenticide zinc phosphide is registered for use in macadamia nut orchards and is relied on by growers to manage rodent damage, but results of operational baiting are variable.

Macadamia nut growers typically broadcast zinc phosphide baits on the orchard floor, although they can also place them directly in burrows or in bait stations on the ground or in trees. The federal registration labels permit application of zinc phosphide baits at any time during the macadamia nut crop cycle, but a 30-day preharvest restriction makes it difficult to coordinate rodenticide baiting with harvest schedules. Most growers in Hawaii apply zinc phosphide baits during the nonharvest season, when mature nuts and competing labor demands are at a minimum. Rats often invade orchards, build their populations, and cause extensive damage during the extended harvest season.

RAT RESEARCH PROGRAM

Trapping as a Damage Control Technique

The Denver Wildlife Research Center field station in Hilo, Hawaii studies the biology, impact, and control of rodent pests in Hawaiian agricultural crops, primarily sugarcane and macadamia nuts. We currently are conducting a trapping study to learn more about the ecology of rats in macadamia orchards and to evaluate this technique as a nonchemical means for reducing rat populations and controlling damage. Although trapping is too labor-intensive for most large-scale agricultural situations, it may be cost-effective for protecting high value crops such as macadamia nuts. The study is a 2-year cooperative project with the Mauna Loa Macadamia Nut Corporation (MLMNC), the world's largest processor of the gourmet nuts. The study is being conducted in 4 blocks encompassing 16–20 ha each and containing 170–220 twenty-year-old macadamia trees per hectare. We randomly selected half of each block for in-tree placement of 20-25 traps/ha.

At approximately 6-wk intervals, during the week following each of 5 harvests in each block, we baited the traps with chunks of coconut, secured them to lower lateral branches, and checked them daily for 2 wk. We shut down the traps for weekends and rebaited them with fresh coconut on Monday of the second week. We removed carcasses and rebaited traps as necessary. We recorded the sex, weight, reproductive condition, and (for females) number of embryos of each rat, and removed and froze the stomachs for later analysis of their contents to determine the food habits of orchard rats throughout the crop cycle.

During the 1990–91 harvest season, we captured a total of 1,706 rats in the 4 blocks, including 1,683 roof rats, 22 Polynesian rats (*R. exulans*), and 1 Norway rat (*R. norvegicus*). Initial trap success during the first trap session ranged from 9.1 to 41.0 rats/ha among the 4 blocks. Trap success in each block declined to less than 5 rats by the end of each 2-wk session, but populations usually increased substantially by the beginning of the next trapping session.

Rats damaged an average of 4.7% of the nuts in the reference sections, compared to 1.6% in the trapped sections. Damage was reduced by an average of from 39 to 81% among the 4 blocks. Overall, damage was 61% less in the trapped sections.

Based on an estimated potential yield of 3,362 kg/ha and a farm price of $1.76/kg of nuts, the reduction in damage due to trapping resulted in estimated average savings ranged from $51.59 to $195.70 per ha and averaged $139.70/ha.

The costs of the project included the price of the traps and the coconut bait, as well as the labor for setting, checking, and rebaiting the traps. Total costs during the first year of the study ranged from about $200 to $280/ha and averaged just over $247/ha among the 4 blocks.

The high cost of conducting the trapping program compared to the estimated savings indicates that this program was not cost-effective for reducing damage. However, because we also collected biological data, the project was more labor intensive than a strictly control program would be. We checked the traps daily to collect and identify carcasses and to preserve stomach samples. During the second year of the study, we hope to improve the cost-effectiveness of the trapping program by checking and rebaiting the traps weekly instead of daily, which should reduce labor requirements by 80%.

Movements of Rats in Orchards

During 1991 we also initiated a radio telemetry study to determine nightly movement patterns of rats in a macadamia nut orchard, to detect seasonal differences in these movements, and to relate seasonal differences to the abundance and maturity of nuts. We are conducting the study during 3 periods of the crop cycle: peak anthesis, peak immature nuts (i.e., when most nuts are >110 days old and full-sized, but without shells), and peak mature nuts (i.e., when nuts are >200 days old and have shells).

During each of these 3 periods, we hope to fit approximately 20 roof rats with collar radio transmitters and monitor their movements during 10 nightly tracking sessions over the course of 3 wk. We plan to determine the location of each collared rat at 2-hr intervals between sunset and sunrise. We will take occasional daytime readings to monitor diurnal activity, to locate nests and daily resting places, to confirm suspected mortality, and to recover detached transmitters.

So far we have tracked 18 rats during peak harvest and 24 rats during peak flowering, but still have to collect data during the peak immature period. Since the study is still in progress, the following observations on patterns in our telemetry data are preliminary. Most of the rats we have monitored remain in underground burrows during the day, emerge shortly after sunset to feed in the canopy, and return to their burrows shortly before sunrise. During peak harvest most rats stayed within 5-10 trees of their daily resting burrows. Nightly movements appear to be more extensive during peak flowering, perhaps in response to the reduced availability of nuts. We have not observed that any of the rats captured in the orchard venture into surrounding windbreaks or noncrop areas, but some of the rats residing in windbreaks forage in trees along the perimeter of the orchard.

The results from this study should help managers devise more effective strategies for controlling rats in their orchards. Knowledge of seasonal and nightly movement patterns of rats in orchards will help determine optimum timing and placement of rodenticide baits, traps, or other control measures in macadamia nut orchards.

Field Evaluation of Zinc Phosphide

During the 1990–91 crop year we have continued to evaluate ways to improve the effectiveness of zinc phosphide baiting during the nonharvest season. We had planned to conduct a study in conjunction with MLMNC's operational baiting program at their orchard in Keaau. Our initial examination work during the harvest season indicated that rat populations in the orchard were high. However, when we initiated the pretreatment trapping and the pretreatment damage assessment, we found that rat populations were too low to proceed with the study. The drastic drop in rat numbers and damage during the nonharvest season may indicate that most rats leave orchards during times of low nut availability, and that baiting at this time is not useful. However, more research involving the entire production cycle is needed to determine seasonal patterns in rat numbers and damage in macadamia nut orchards to help devise more effective management strategies.

Laboratory Bait Efficacy Studies

Our staff conducts routine laboratory feeding trials to evaluate candidate and registered rodenticides. Roof rats are the major rodent pest in macadamia nut orchards; Norway rats and Polynesian rats cause extensive damage in sugarcane fields. We conduct tests with all 3 species.

The rats used in the studies described here were captured in forested areas, sugarcane fields, and associated noncrop areas in Hawaii and isolated and acclimated to laboratory conditions for a minimum of 21 days before testing. During quarantine, captive animals had access to rodent laboratory chow (Purina Mills®, Inc.) and water *ad libitum* and were maintained according to standard procedures. At the end of the quarantine period, animals that appeared normal and healthy were transferred to the test room. Both quarantine and test rooms were maintained at about 25°C on a 12 h light/12 h dark cycle.

The general procedures for all feeding trials were the same. Five rats of each species and sex were randomly assigned by weight to each treatment group. During no-choice trials, we replaced the laboratory chow in each cage with a bowl of test food and placed a tray under each cage to catch spillage. During free-choice trials, animals also had access to rodent laboratory chow. Uneaten and spilled test food was collected and weighed daily, and living rats were offered fresh test rations. At the conclusion of a feeding trial, the maintenance diet of laboratory chow was returned to the cages. During the feeding trials and for 10 days posttreatment, animals were checked daily for mortality and signs of toxicosis.

We estimated daily consumption by subtracting the combined weight of uneaten and spilled food (adjusted for moisture loss or gain) from the weight of the food offered to each animal. Changes in the weight of the test food due to moisture loss or gain were estimated daily by placing 3 bowls of each test food in the test room at the same time that the test food was offered to the rats, and removing and reweighing them 24 h later. Total consumption for each rat for the entire test was the sum of its daily consumption.

Wax bait blocks—Zinc phosphide-treated oats are the bait most commonly used to control rats in macadamia nut orchards and sugarcane fields, but they rapidly lose their potency under the wet and humid conditions present in much of Hawaii (Hilton 1971), especially in thick sugarcane mats and heavily canopied macadamia nut orchards. To determine whether a waxed bait block might be more effective, we conducted 3-day no-choice feeding trials to compare the efficacy of 1) Ridall-Zinc® Bait Block (a waxed grain bait treated with 2.0% zinc phosphide, Lipha Tech, Inc.), 2) 1.88% zinc phosphide-treated oat groats, and 3) untreated oat groats. Reference to commercial products in this paper is for identification purposes only and does not indicate endorsement by the author, the U.S. Department of Agriculture, or cooperators.

Mortality (number of rats that died/number tested) for groups offered bait blocks and treated oat groats, respectively, was 1/10 and 4/10 for Norway rats, 8/10 and 7/10 for roof rats, and 8/10 and 6/10 for Polynesian rats (Table 1). Both zinc phosphide baits were more effective for roof rats and Polynesian rats than for Norway rats (Table 1). The similar performance of the 2 baits indicates that the wax formulations may be as effective as oat groats for controlling damage by roof rats and Polynesian rats in macadamia nut orchards and sugarcane fields. Field testing is needed to verify these results.

Anticoagulant bait evaluation—Hawaiian growers occasionally use anticoagulant baits around the periphery of macadamia nut orchards and sugarcane fields to reduce invasion by rats from surrounding noncrop areas. We recently evaluated 3 commercial anticoagulant bait formulations with 14-day feeding trials: 1) Eaton's® All-Weather Bait Block (0.005% diphacinone, J. T. Eaton, Inc.), 2) KFE Double XX Pival Prepared Rat Bait (0.025% pival, Kawamura Farm Enterprises, Inc.), and 3) Rozol® Paraffin Block (0.005% chlorophacinone, Lipha Tech, Inc.).

At the beginning of the feeding trial, we offered each test animal one of the following baits: 1 section (approximately 60 g) of Eaton's bait block, 2) 1 section (approximately 60 g) of Rozol paraffin block, 3) 20 g (Norway and roof rats) or 10 g (Polynesian rats) of pival grain bait, or 4) 20 g (Norway and roof rats) or 10 g (Polynesian rats) of untreated oat groats. Water and rodent laboratory chow were available *ad libitum* throughout the test. We collected and weighed all uneaten and spilled bait and offered fresh pival and untreated oats daily, but replaced the Eaton's and Rozol bait blocks only when most of the bait was consumed (when the amount of bait remaining was less than 20 g for Norway and roof rats, or less than 10 g for Polynesian rats). We also supplied new bait blocks when it appeared that rats had consumed most of the grain portion of the block. We did not monitor consumption of the rodent laboratory chow.

Mortality for groups offered toxic bait ranged from 80-100% for roof rats, from 60-90% for Polynesian rats, and from 40-80% for Norway rats (Table 2). Animals that died generally succumbed within 6-7 days. All 3 toxic baits produced high percentages of mortality among roof rats, and Eaton's bait block and pival resulted in high mortality of Polynesian rats. However, only the pival grain bait resulted in >50% mortality among Norway rats. Consumption by Norway rats was similar among the 3 baits, but mg ingested/kg of body weight was much lower for the bait blocks, perhaps

Table 1. Mean consumption (SE) and mortality of rats during 3-day no-choice feeding trials to evaluate 2 zinc phosphide baits. Each bait was offered to 5 males and 5 females of each species.

Bait	Mean initial body wt (g)	Consumption (g) Day 1	Consumption (g) Total	Mean (SE) zinc phosphide ingested (mg/kg)	No. died/ no. tested	Days to death Mean	Days to death Range
Rattus norvegicus							
Untreated oats[a]	203	12.4 (1.0)	40.2 (1.7)	0.0 —	0/10	—	—
Treated oats[b]	201	1.3 (0.3)	1.8 (0.3)	174.1 (28.4)	4/10	2.7	2-4
Ridall-Zinc[c, d]	208	0.6 (0.2)	0.7 (0.2)	59.4 (12.7)	1/10	1.0	—
Rattus rattus							
Untreated oats	168	9.1 (1.1)	29.9 (2.4)	0.0 —	0/10	—	—
Treated oats	166	1.1 (0.2)	1.1 (0.2)	128.8 (29.0)	7/10	1.3	1-4
Ridall-Zinc	168	1.4 (0.2)	1.4 (0.2)	158.8 (22.0)	8/10	1.0	1-1
Rattus exulans							
Untreated oats	72	4.1 (0.6)	14.8 (0.9)	0.0 —	0/10	—	—
Treated oats	74	0.4 (0.1)	0.5 (0.1)	120.7 (21.0)	6/10	1.2	1-2
Ridall-Zinc	74	0.4 (0.1)	0.4 (0.1)	94.0 (9.3)	8/10	1.0	1-1

[a]Oat groats with 2.0 % Alcolec-S.
[b]Oat groats with 1.88 % zinc phosphide and 2.0 % Alcolec-S.
[c]Waxed bait block (Lipha Tech, Inc.) with 2.0 % zinc phosphide.
[d]Reference to commercial products is for identification purposes only and does not imply endorsement by the author, the U.S. Department of Agriculture, or cooperators.

Table 2. Mean consumption (SE) of 3 anticoagulant baits and mortality of rats during 14-day feeding trials. Each bait was offered to 5 males and 5 females of each species.

Bait	Mean initial body wt (g)	Consumption (g)	Mean (SE) AI ingested (mg/kg)	No died/ no. tested	Days to death	
					Mean	Range
Rattus norvegicus						
Eaton's bait block[a,b]	195	34.6 (6.4)	10.0 (2.0)	4/10	6.7	5-8
Pival grain bait[c]	187	41.5 (5.2)	62.6 (9.9)	8/10	6.2	4-8
Rozol paraffin block[d]	195	34.4 (10.2)	8.7 (2.6)	5/10	7.0	6-8
oat groats	191	184.4 (14.0)	—	0/10	—	—
Rattus rattus						
Eaton's bait block	168	28.4 (6.7)	8.6 (2.0)	9/10	6.0	4-9
Pival grain bait	160	27.9 (4.1)	46.1 (7.1)	10/10	6.7	5-12
Rozol paraffin block	166	58.5 (10.2)	17.2 (2.5)	8/10	7.6	5-12
oat groats	169	120.6 (8.6)	—	0/10	—	—
Rattus exulans						
Eaton's bait block	71	11.8 (2.4)	8.6 (1.8)	9/10	7.1	6-12
Pival grain bait	66	17.2 (1.8)	68.9 (8.4)	9/10	6.7	3-10
Rozol paraffin block	69	21.6 (3.3)	16.5 (2.5)	6/10	6.7	3-12
oat groats	67	73.8 (4.5)	—	0/10	—	—

[a]0.005 % diphacinone (2-diphenylacetyl-1, 3-indandione).
[b]Reference to commercial products is for identification purposes only and does not imply endorsement by the author, the U.S. Department of Agriculture, or cooperators.
[c]0.025 % pival (2-pivalyl-1,3-indandione).
[d]0.005 % chlorophacinone (2-[(p-chlorophenyl) phenylacetyl]-1,3-indandione).

Table 3. Mean consumption (SE) of bromethalin-treated oats and mortality during 3-day no-choice feeding trials. Each bait was offered to 5 males and 5 females of each species.

Concentration (%)	Mean initial body wt (g)	Consumption (g)		Mean (SE) bromethalin ingested (mg/kg)	No. died/ no. tested	Days to death	
		Day 1	Total			Mean	Range
Rattus norvegicus							
0	199	11.7 (2.1)	40.6 (3.3)	0.0 —	0/10	—	—
0.005	198	10.9 (0.7)	11.1 (0.7)	2.9 (0.3)	6/10	1.2	0-2
0.010	203	6.8 (0.8)	7.7 (0.5)	4.0 (0.4)	9/10	1.8	0-4
0.020	187	3.9 (0.5)	4.2 (0.4)	4.7 (0.5)	10/10	1.7	1-3
Rattus rattus							
0	174	12.1 (1.7)	37.2 (3.7)	0.0 —	0/10	—	—
0.005	178	9.6 (1.0)	12.4 (1.1)	3.6 (0.4)	7/10	4.4	0-12
0.010	173	5.3 (0.9)	7.2 (0.8)	4.2 (0.4)	10/10	3.1	2-8
0.020	167	4.4 (0.5)	4.6 (0.5)	5.4 (0.4)	8/10	1.5	0-2
Rattus exulans							
0	72	5.2 (0.5)	16.8 (1.0)	0.0 —	0/10	—	—
0.005	73	3.6 (0.7)	4.6 (0.3)	3.2 (0.2)	10/10	2.4	1-4
0.010	74	2.4 (0.5)	3.2 (0.2)	4.5 (0.3)	10/10	2.1	1-3
0.020	70	2.0 (0.4)	2.3 (0.3)	6.7 (0.8)	10/10	1.8	1-3

reflecting formulation differences. This study suggests that all 3 anticoagulant baits could be used for reducing invasion of macadamia nut orchards by roof rats. Field studies should be conducted to develop operation procedures.

Candidate rodenticides—We conducted 3-day no-choice feeding trials to evaluate bromethalin for use with each of the 3 species of rats. This rodenticide is registered for commensal rodent control in and around structures, but it may also be effective for agricultural use (Jackson et al. 1982, Dreikorn and O'Doherty 1984). We tested 4 concentrations (w/w) of bromethalin on oat groats: 0%, 0.005%, 0.01% (the concentration registered for commensal use), and 0.02%.

Mortality of Norway rats ranged from 0 to 100% and increased with increasing concentration of bromethalin (Table 3). Average mean days to death ranged from 1.2 days to 1.8 days. All Polynesian rats offered bromethalin-treated oats died, regardless of concentration (Table 3). Average mean days to death ranged from 1.8 to 2.4 days. Mortality of roof rats was 70% in the lowest bromethalin group, 100% in the 0.01% group, and 80% in the 0.02% group (Table 3). Average mean days to death ranged from 1.5 to 4.4 days. Average consumption for all groups offered bromethalin-treated oats was greatest on Day 1; thereafter, it declined sharply or ceased. Although consumption generally declined with increasing concentration of bromethalin, in most cases the amount of bromethalin actually ingested (mg AI/kg body weight) increased (Table 3).

Bromethalin appears to have potential for effective use with all 3 species. Field evaluation of this material is warranted.

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